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Title	:	"A system and a method for predicting and handling slugs in a flowline system."

P02069

The present invention relates to a method and a system for predicting and handling hydrodynamic and terrain-induced slugs being transported in a multiphase flowline.

The method and the system according to the present invention can be adapted to any production system transporting a multiphase fluid towards a downstream process including a separator (two- or three-phase) or a slug catcher at the inlet, in which there is regulation of both pressure and liquid level(s). The multiphase fluid normally consists of a mixture of an oil (or a condensate) phase, gas and water.

A typical production system where the present invention could be implemented includes multiphase transport from platform wells, from subsea wells towards a subsea separator, from a subsea production template towards an offshore platform including a riser, between offshore platforms, from a subsea production system towards an onshore process facility or between onshore process facilities.

Depending on fluid properties, flowline characteristics and superficial velocities of the different fluid phases, a multiphase production system might give what is known as slug flow, experienced as fluctuating mass flow and pressure at the production system outlet. Further, if these slugs are "large" compared to the design of the downstream equipment, the fluctuations could propagate into the process and reach a level untenable to the operators. As a consequence, and as a precaution to avoid a process trip, there are numerous examples where multiphase production lines have been choked down due to incoming slugs.

Slugs are normally initiated in two ways that are fundamentally different. Terrain-induced slugs are caused by gravity effects when the velocity differences, and thus the interfacial friction, between the separate fluid phases is too small to allow the lightest fluid(s) to counteract the effect of gravity on the heavier fluid(s) in upward inclinations. Hydrodynamic slugs (identified in a flow regime envelope as a function of the pipe angle and the superficial fluid velocities for a given fluid) are formed by waves growing on the liquid surface to a height sufficient to completely fill the pipe. Because of differences in the velocities of the various fluid phases up- and downstream of this hydrodynamic slug, an accumulation of liquid and thus a dynamic slug growth can occur.

Hydrodynamic slugs too are affected by the flowline elevation profile, since their formation and growth depend on the pipe angles. Note, however, that an obvious way to prove the distinction between terrain-induced and hydrodynamic slugs is that hydrodynamic slugs could be formed in 100% horizontal flowlines (sometimes even in downwards inclination), whereas terrain-induced slugs somehow need upwards inclination.

Slugging is by definition a transient phenomenon, and steady state conditions are hard to achieve in a slugging flowline system. In such a system, hydrocarbon liquid (alternatively water or a hydrocarbon/water mixture) accumulates along the production system and the slugs will at some point reach the flowline exit. Between these slugs, there will be periods where small amounts of liquid exiting the system and the process will more or less receive a single gas phase, also described as gas slugs.

In order to overcome process disturbances due to slugging (terrain-induced or hydrodynamic), three methods have traditionally been used in multiphase transportation systems:

- Reduce the flow rate and thereby the slug volumes within the limits of the downstream process, by throttling the inlet choke or by selecting a smaller flowline diameter in the design phase
- Prolong start-up time or ramp up time when changing flow rates
- Increase if possible the dimensions of the downstream process (i.e. slug catcher, alternatively the 1st stage separator)

These "traditional" methods will either reduce production from the flowline systems in question or increase the costs and dimensions of the downstream process. Additionally, even if accounted for, slugs might grow larger than expected or could occur at unfortunate moments compared to actual process capabilities. As a consequence, the pressure and flow fluctuations could result in process shut-downs, which might have significant financial impacts.

Since every gas and oil producer wants to optimise the operating conditions of their process plants, there have been several attempts to find improved solutions to overcome process perturbations caused by slugging in the upstream production system.

US Patent No. 5544672 describes a system for mitigation of slug flow. It detects incoming slugs upstream of the separator and performs a rough calculation of their respective volumes. These slug volumes are thereafter compared with the liquid handling capacity of the separator. If the estimated volume of the incoming slugs exceeds the liquid slug handling capacity of the separator, a throttling valve located upstream of the separator is choked.

This solution has the advantage that it is simple and could be used for both hydrodynamic as well as terrain-induced slugs, since it is located downstream of the point where slugs are generated. However, the system entails some major disadvantages:

- Since the flow rate is being throttled down, it has negative impact on the production and thereby the field economics.
- It does not take use of the slug handling capacity in the downstream process.
- It does not describe how gas slugs are identified and treated. As a consequence pressure fluctuations in the separator due to incoming gas slugs must still be solved by gas flaring.
- The system does not separate water slugs from hydrocarbon (HC) liquid slugs which could give process perturbations downstream of a three-phase separator.
- It prolongs the start-up time after system shut-down, since the production is being throttled down every time a liquid slug is present.

International Patent Application WO 01/34940 describes a small (mini-) separator located at the top of the riser just upstream of the 1st stage separator. Slugs are either suppressed by volumetric flow controller or liquid flow controller mode, depending on the slug characteristics. Regulation is achieved by two fast acting valves on the gas and liquid outlet streams downstream of the mini-separator, based on pressure and liquid level data from the mini-separator as well as flow rate measurements of its outlet streams.

Moreover, the International Patent Application WO 02/46577 describes a model-based feedback control system for stabilization of slug flow in multiphase flowlines and risers. The system consists of a single fast acting valve located at the outlet of the transport system, i.e. upstream of the separator. The opening of this valve is adjusted by a single output control signal from the feedback controller that uses continuously monitoring of pressure upstream of the point where slugs are generated as the main input parameter. This control system is specially suited for terrain-induced slugs since any liquid accumulation is detected by pressure increase upstream of the slug (due to static pressure across the liquid column). However, the system does not show the same performance for slugs which are hydrodynamic by nature since these slugs could be formed in perfectly horizontal flowlines, giving no build-up of pressure upstream of the slug.

Briefly, for the two latter slug control systems, fast acting equipment located at the outlet of the transportation system, in combination with quick response time of the control loops are used to suppress development of slugs, by immediately counteracting the forces contributing to slug growth.

However, these solutions too entail several disadvantages:

- As for the slug mitigation system they do not take use of the slug handling capacity in the downstream process.
- The control system described in WO 02/46577 does not cater for hydrodynamic slugs, while the system described in WO 01/34940 handles slugs which are terrain-induced by nature far better than hydrodynamic slugs.
- They are normally not self-regulating for any operational range in the transport system, and the systems require manual input from an operator or must be de-activated during some of the normal production scenarios.
- They both require fast acting valve(s) in combination with quick response time of the control loops.
- They generalise on flowline systems including vertical piping (i.e. risers or tubing) at the outlet of the transport system.
- The system described in WO 01/34940 requires topside equipment and could be costly, especially in case of weight being an issue.

Generally speaking, none of the existing systems fully integrates the transport system and the downstream process. Hence, they do not cover the full range of incoming slugs including hydrodynamic slugs as well as gas and water slugs. Finally, their application is limited to a narrow operating range and they require manual input or de-activation at some time.

In light of the shortcomings mentioned above, the inventors have found that there is need for a more efficient method and system for prediction and handling of slugs. The present invention describes a method and a system applicable in connection with a downstream process in which disadvantages of former systems

have been eliminated. The basic idea is to fully integrate the production system and the downstream process. The main advantages of the invention is that it utilizes the hole downstream process for slug handling and it applies to any kind of slug normally presented in a multiphase flowline system independent of type or nature of the slug. It will also cover any operating range if it is properly designed.

In accordance with the present invention, this object is accomplished in a method of the above kind in that said method comprises the following steps: detecting said slug downstream of the point for slug initiation and upstream said process by means of a slug detector, determining and measuring all main characteristics of said slug by means of a computer unit that receives all signals from said slug detector, receives signals from all instruments needed for regulation of pressure and liquid levels from every separator in the liquid trains of the entire downstream process, determines the nature of every incoming slug and predicts its arrival time to said separator or catcher and corresponding volume and compares it with the actual slug handling capability of said process, processes all its incoming data in order to find an optimum regulation of said downstream process so that process perturbations due to incoming slugs are reduced to a minimum throughout the entire process, achieves its regulation of said process by means of choke adjustments or by adjusting the speed of compressors or pumps connected to each separator.

Furthermore, in accordance with the present invention, this object is accomplished in a system of the above kind in that the system comprises a slug detector 1 located downstream of the point for slug initiation and upstream of said process inlet including instrumentation dedicated to determine and measure the main slug characteristics of every incoming slug, a computer unit 4 integrating said flowline system and said downstream process including software which determines the type of the slug, its volume and predicts its arrival time into said downstream process.

The present invention will be described in further detail in the following figures, where:

Figure 1 shows a process diagram of the present invention in its simplest form implemented in an offshore production system producing towards an onshore process including a vertical two-phase slug catcher 8 at the inlet of said process. It is further seen that the slug catcher pressure 3 is controlled by adjustment of a gas outlet valve 6. Correspondingly, its liquid level 9 is controlled by adjustment of a liquid outlet valve 7.

A simple description of the invention is as follows: The distance 2 between the slug detector 1 and the process has been optimised with respect to the process and its parameters for regulation. When the slug detector 1 detects a liquid slug, the computer unit 4 determines its nature and calculates its arrival time and volume. Based on this information and the current liquid level 9 in the slug catcher 8, the computer unit immediately gives signal to the liquid valve 7 to start liquid draining of the slug catcher 8, prior to slug arrival. When the liquid slug finally arrives at the slug catcher, the liquid level will already be adjusted to near low alarm, and the liquid outlet valve 7 will be nearly fully opened. Moreover, when the slug tail is detected, the liquid valve 7 starts closing before the slug tail enters the separator. Correspondingly, when a gas slug is detected, measures are taken to reduce slug catcher pressure 3 by opening the gas outlet valve 6. Thus the forces that contribute to slug growth will be counteracted and at the same time the process will take care of the incoming slug. Hence, the invention optimises the slug handling capacity of process, and the operator will see reduced perturbations in the process. Depending on which option is used for determination of the fluid velocities, a multiphase meter or flow transmitter 5 is included upstream of the topside choke 19.

Figure 2 shows a simplified process diagram of the present invention implemented in an offshore production system including a riser 13, producing towards a horizontal three-phase separator 8, not including the hydrocarbon liquid train downstream of the separator. As in Figure 1 the distance 2 between the slug detector 1 and the process has been optimised with respect to the process and its parameters for regulation. An alternative location 10 of the slug detector as part of the riser is also indicated for deep-water developments. In this example it is seen that the separator pressure 3 is regulated by adjustments of the gas compressor speed 14. Moreover, the hydrocarbon liquid level 9 is regulated by speed control of the downstream pump 15. Regulation of the water level 11 is achieved by means of an outlet valve 12. Basically, the said regulation of the system is performed very similar to the example given in Figure 1, but instead of using outlet valves for regulation of the pressure 3 and liquid level 9, the computer unit 4 gives input to the gas compressor 14 and oil pump 15 speed controls, respectively. In this production system, water slugs are detected because they are denser than oil/condensate slugs besides having a lower content of gas. Depending on which option is used for determination of the fluid velocities, a multiphase meter or flow transmitter 5 is included upstream of the topside choke 19.

Figure 3 shows a simplified process diagram of the present invention implemented in an offshore production system including a riser 13 and a horizontal three-phase separator 8 at the process inlet. Opposed to the first two figures, the downstream liquid train is included, and it includes a second separator 9 in addition to the first one 8. It is seen that the computer unit 4 is used for regulation of pressure and liquid level in the entire hydrocarbon liquid train, and hence the entire process takes part in the slug treatment. The separator pressures 3 and 16 are both regulated by means of valves on the gas outlet 6 and 17. The liquid levels 9 and 18 are controlled by means of a valve on the liquid outlet 7 of the first separator 8 and a pump 15 on the liquid outlet of the second separator 9. Regulation of the water level 11 is achieved by means of an outlet valve 12. As for the other two figures, the distance 2 between the slug detector 1 and the process has been optimised with respect to the process and its parameters for regulation.

Depending on which option is used for determination of the fluid velocities, a multiphase meter or flow transmitter 5 is included upstream of the topside choke 19.

It is important that the computer unit 4 also includes normal (traditional) pressure and level regulation of each separator unit in the process in case the pressure or liquid level(s) pass their alarm levels, approaching their trip levels. During such circumstances, there might be a need to de-activate the regulation.

When utilising the present invention the incoming slugs (terrain-induced or hydrodynamic by nature) are detected at an early stage by instrumentation 1 dedicated to define the slug characteristics. While e.g. WO 02/46577 bases its control on measurements of pressure and temperature upstream of the point where slugs are generated (in order to suppress slug formation if any pressure build-up is recorded), it is essential for the present invention that the instrumentation is located downstream of the point of slug formation, since its intention is to describe the slug characteristics. The very simplest way to define the slug characteristics is by use of a densitometer as described in US Patent No. 5544672, but the instrumentation could easily be extended for more sophisticated information. Online information of the fluid mixture density is used for determination of:

- Liquid slug front
- Liquid slug tail
- Nature of slug:
    - A very high density gives indication of a water slug.
    - A high density gives indication of a HC liquid slug.
    - A low density gives indication of a gas slug.

In addition to a densitometer, the basic instrumentation according to the present invention includes registration of the differential pressure (dP) between the slug detector and the process arrival as a precaution if slugs should be formed downstream of the slug detector. Including more complex instrumentation will further optimise the detector, as long as the production system remains pigable. In

particular, additional information on the on-line water cut in combination with the local hold-up or void fraction as well as fluid velocities of the different phases would be valuable input to the computer unit 4, and so is a multiphase meter 5 at the flowline outlet.

The location 2 of the slug detector must be sufficient for the downstream process to respond adequately prior to slug arrival. Hence, this location 2 needs to be optimised for every new implementation, since it very much depends on the actual production system. It is believed that an optimum location will be within 3 km from the process inlet, giving the computer unit sufficient time to react upon incoming slugs. One exception applies to large gas, condensate systems producing towards an onshore installation where the volume of the slug catchers sometimes is very significant. Note also that for extreme deep-water developments, the optimum location could be somewhere inside the riser itself as seen in Figure 2 by 10 and not necessarily in the subsea flowline or at the riser bottom.

In short, the basic principle of the present slug detector is quite similar to the one described in US Patent No. 5544672. The main improvements are as follows:

- In order to optimise the performance of the computer unit, the location of the slug detector must be adapted to the slug handling capabilities of the downstream process.
- The detector must make the distinction between hydrocarbon liquid slugs and water slugs.
- Therefore, in addition to the densitometer, the slug detector includes a measurement of one of the following parameters: Gas void fraction, local liquid hold-up or water cut

The slug detector sends its signals to the computer unit 4, which constitutes the main component of the present invention. It collects all incoming information from the slug detector as well as the main process parameters of the downstream liquid train. Its overall purpose is to calculate (for every incoming slug):

a) The estimated arrival time for the incoming slug
b) The slug volume
c) The nature of the slug (i.e. water slug, hydrocarbon liquid slug or gas slug) and thereafter optimise the regulation of the downstream process

The computer unit, which preferably includes an on-line transient thermohydraulic simulator, includes three options to define the fluid velocitie(s) and thereby the estimated slug arrival time. Firstly, it could be estimated by manual input, but then some operating scenarios would require de-activation of the system and thereby use of traditional (i.e. manual) methods for slug control. The second alternative is to calculate the fluid velocitie(s) by use of the thermohydraulic flow simulator, where a multiphase meter at the flowline outlet 5 will improve the performance of the computer calculations. Finally, the velocities of the different fluid phases could be determined based on on-line ultrasonic measurements, located somewhere between the slug detector and the process arrival.

The prediction of reliable slug volumes is obtained through an integral module. Based on information of the slug front, slug tail, mixture density, the fluid velocities defined above and one of the following: water cut, gas void fraction or local hold-up, the computer unit will give accurate estimates of the slug arrival times and their corresponding volumes.

When all the slug characteristics have been described, the output signals from the computer unit will be optimised and adjusted to reduce the process perturbations in the downstream HC liquid train to a minimum.

The present invention describes a solution for slug treatment that has a number of advantages compared to already known solutions:

- Since the main slug characteristics of all incoming slugs are known before they enter downstream equipment, it is easy to take corrective measures to reduce fluctuations and perturbations in the entire process.
- It applies to any type of slug independent of whether it is hydrodynamic by nature or terrain-induced and regardless whether it is a liquid, water or a gas slug.
- It links the transport system and the downstream process and thereby makes use of all the slug handling capacity in the entire downstream process.
- It applies to any production system of multiphase transport, regardless whether it is a well or if it is a subsea, topside or onshore installation.
- Basically, a single computer unit is sufficient for control of a production facility receiving incoming slug flow from different sources.
- It will shorten the start-up time after shut-down or for variations of flow rate.
- There is no need for fast acting valves.
- If properly designed it will reduce the risk of process shut-downs due to slug flow.

CLAIMS:

1. A system for predicting and handling slugs of any kind being formed in a flowline system transporting a multiphase fluid towards a downstream process including a separator or a slug catcher at said process inlet,

   characterised in that

   said system comprises:

   a slug detector (1) located downstream of the point for slug initiation and upstream of said process inlet including instrumentation dedicated to determine and measure the main slug characteristics of every incoming slug,

   a computer unit (4) integrating said flowline system and said downstream process including software which determines the type of the slug, its volume and predicts its arrival time into said downstream process.

2. A system according to claim 1,

   characterised in that

   the slug detector comprises instrumentation in said flowline for measuring fluid pressure, mixture density and at least one of the three following parameters: gas void fraction, water cut or local hold-up.

3. A system according to claim 1,

   characterised in that

   the distance (2) from the slug detector (1) to the downstream process is for every new implementation optimised with respect to the slug handling capabilities of said process and the parameter settings of all regulators being controlled by said computer unit (4).

4. A system according to claim 1,
characterised in that
the optimum location for said detector could either be in said flowline some distance (2) upstream of the receiving process or within the riser (13).

5. A system according to claim 1,
characterised in that
the computer unit includes three options for defining the fluid velocities; by manual input, by on-line registration using ultrasonic meters, or by including an on-line transient simulator in combination with a multiphase meter at the flowline outlet (5).

6. A system according to claim 1,
characterised in that
the computer unit comprises override functions that override or suppress the slug control regulation of the downstream liquid train if the trip levels of the separators are approached.

7. A method for prediction and handling slugs of any kind being formed in a flowline system transporting a multiphase fluid towards a downstream process including at least one separator or slug catcher at said process inlet,
characterised in that

said method comprises the following steps:

detecting said slug downstream of the point for slug initiation and upstream said process by means of a slug detector,
determining and measuring all main characteristics of said slug by means of a computer unit that receives all signals from said slug detector,
receives signals from all instruments needed for regulation of pressure and liquid levels from every separator in the liquid trains of the entire downstream process,

determines the nature of every incoming slug and predicts its arrival time to said separator or catcher and corresponding volume and compares it with the actual slug handling capability of said process,
processes all its incoming data in order to find an optimum regulation of said downstream process so that process perturbations due to incoming slugs are reduced to a minimum throughout the entire process,
achieves its regulation of said process by means of choke adjustments or by adjusting the speed of compressors or pumps connected to each separator.

8. A method according to claim 7,
characterised in that
all signals from said slug detector (1) are transferred and used as input by said computer unit which uses this information to determine the type of the slug (i.e. hydrocarbon liquid, water or gas), its volume and predicts its arrival time into said downstream process.

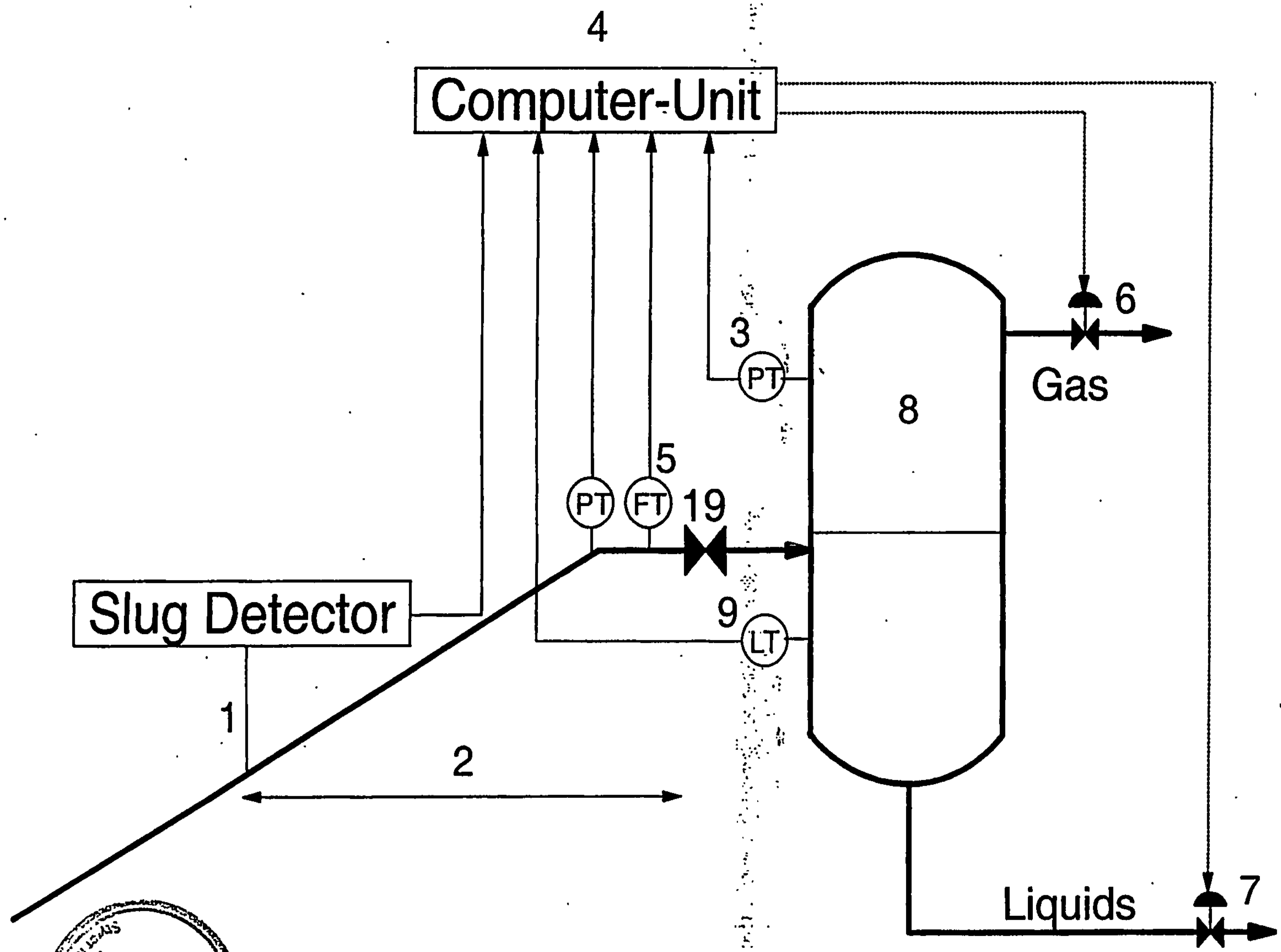
9. A method according to claim 7,
characterised in that
in addition to receiving all information from said slug detector, the computer unit receives information from all instruments needed for regulation of pressure and liquid in all separators of the liquid train in the downstream process.

10. A method according to claim 7,
characterised in that
all separators in an entire liquid train are regulated by use of the computer unit when slugs originating from one or several transport systems is entering the first separator of the said train. Only one computer unit will be required even though the slug flow could originate from several transport systems

11. A method according to claim 7,
characterised in that
the computer unit achieves its regulation throughout the entire process by means of choke opening adjustments or by adjusting the speed of compressors or pumps being used for regulation of pressure and liquid levels in the liquid train of the downstream process.

ABSTRACT:

The present invention relates to a system and a method for prediction and handling slugs of any kind being formed in a flowline system transporting a multiphase fluid towards a downstream process including a separator or a slug catcher at said process inlet. Said system comprises a slug detector (1) located downstream of the point for slug initiation and upstream of said process and a computer unit (4) integrating said flowline system and said downstream process including software which determines the type of the slug, its volume and predicts its arrival time into said downstream process.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Computer-Unit
Slug Detector
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Gas
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Liquids
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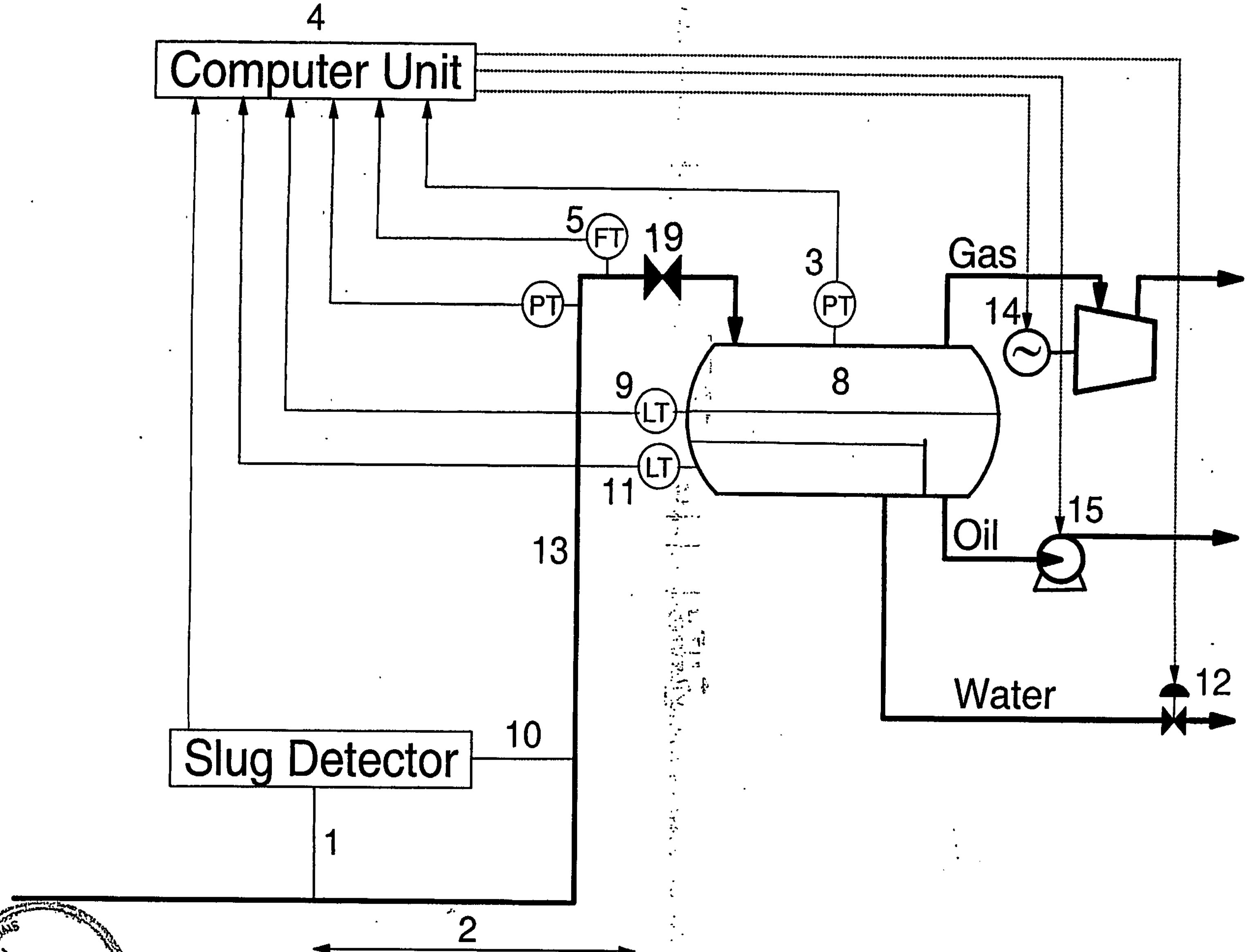
Fig. 1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Slug Detector
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Fig. 2

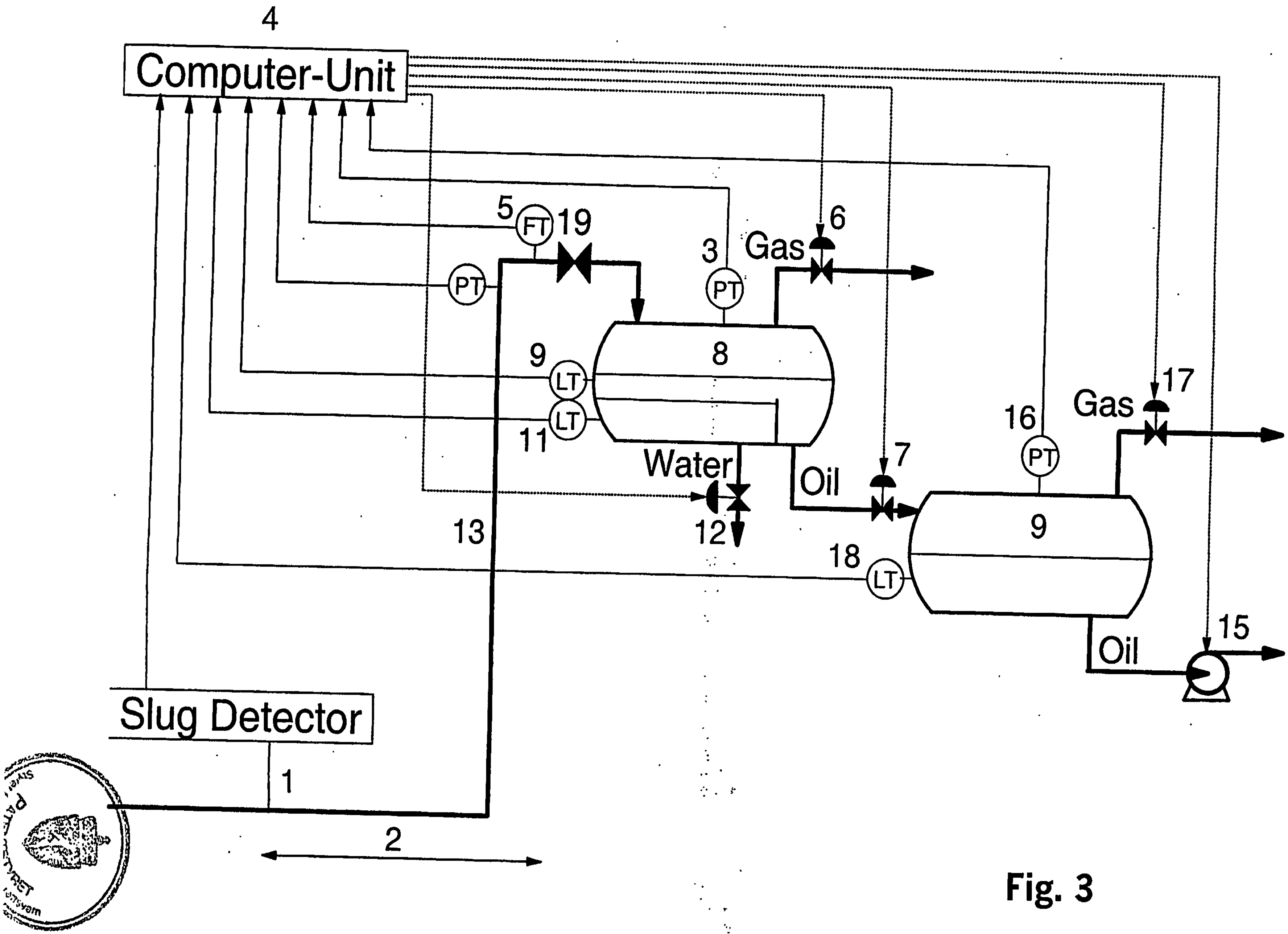
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Fig. 3